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Economical Analysis of a Groundwater Source Heat Pump with Water Thermal Storage System

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Abstract: The paper is based on a chilled and heat source for the building which has a total area of 140000m^2 in the suburb of Beijing. By comparing the groundwater source heat pump of water thermal storage (GHPWTS) with a conventional chilled and heat source scheme in economical, technical, and environmental aspects, it is determined that the scheme of the groundwater source heat pump has better energy efficiency than others. The GHPWTS can take full advantage of the heat source from groundwater and benefit of electricity difference pricing during a day. Its character is a combination of a strength and another strength. It is the lowest cycle cost of all chide and heat source schemes. The GHPWTS has the best economic benefit and runs stably and reliably. Its advantage is clearly compared with other schemes. There is a real value for the project that is similar to the characteristic of this project and the condition of the water source.

Key words: Water Thermal Storage; Groundwater Source Heat Pump(GWHP); economical analysis social benefit

1. INTRODUCTION

The demand for electricity during the on-peak hours is getting larger than the off-peak hours with the increasing number of HVAC applications and the building energy efficiency in china is more and more urgent. Using efficient and environment-friendly air conditioning system is a available approach to realize building energy efficiency. The groundwater source heat pump system can get high Coefficient of Performance because it makes use of groundwater as low-level heat energy. Thermal storage system can balance the electric demand and reduce operating cost. In this paper, the Economical of Groundwater Source Heat Pump with Water Thermal Storage system for a commercial building in Beijing was analyzed.

2. PROJECT SUMMARY

This project lies in Changping district of Beijing. The building area is 143341.8 square meters. The air-conditioning space is 100000 square meters. There are two floors under the ground and eleven floors above the horizon. The equipment room and parking plaza lie in underground floor. The first floor to the third floor are marketplaces, the fourth to the eleven are used as entertainment and work room. The peak cooling load of the entire building is 14643.0KW, the peak heating load is 5755.6KW (a callback equipment is designed to reclaim thermal energy and counteract parts of heating loads) . There are 214 cooling days and 121 heating days in a year according to investigation. The fire protection flume is set up in the second underground floor with 500 stere.

3. PROJECT DESIGN

According to careful analysis, we put forward two kinds of feasible schemes. The scheme one is a conventional system (chiller and gas-fired hot water boiler) and the scheme two is a Groundwater Source

Heat Pump combined with water thermal storage system.

3.1 Scheme One: Conventional System

The capacity of chillers and boiler is decided by the maximal load on peak day of cooling and heating . Source side has a constant flow and load side a variable flow in the cold and heat water system with a single-stage pump mode. The temperature of chilled water is designed as 7/12□. We choose four three-stage centrifugal chillers of CVHG-1067 type which capacity is 1100RT. Chilled water pumps and chillers, cooling water pumps and cooling towers are designed as one to one operated mode.

The hot water for heating is provided by gas-fired hot water boiler. Choose two CWNS01.75-95/70 and one CWNS02.8-95/70 gas-fired hot water boilers and two operating pressure 0.8MPa plate heat exchangers. The temperature of hot water supply/return is 60/50℃.the conventional system is mature and reliable technique.

Other important equipments as Tab.1:

Tab.1 The Equipments of scheme one

Equipment	Number	Electric motor power (KW)	Flow (m^3/h)
Chiller water pump	4	90	690
Cooling water pump	4	75	810
Heating water pump-1	2	22	65.4
Heating water pump-2	2	30	100
Cooling tower	8	11	400

3.2 Scheme Two: Groundwater Source Heat Pump Combined with Water Thermal Storage

3.2.1 Feasibility analysis

Groundwater Source Heat Pump is identical with Heat Pump in principle, but groundwater is used as low-level thermal source. In summer cooling cycle, condensation temperature can be lowered because groundwater temperature is far lower than outdoors air temperature. In winter heating cycle, evaporation temperature can be heightened because groundwater temperature is far higher than outdoors air temperature. So the Coefficient of Performance of Heat Pump can be enormously heightened and the ratio of conversion between electricity and thermal energy can attain 3~4. Groundwater Source Heat Pump can economize operating costs to 20%~30% than Air Source Heat Pump. The temperature of groundwater is comparatively steady-going in whole years, this can guarantee a reliable and steady operating about the Heat Pump system. In this system groundwater circulates in an entirely close cycle without loss of groundwater, so it belongs to a environment-friendly and efficient system.

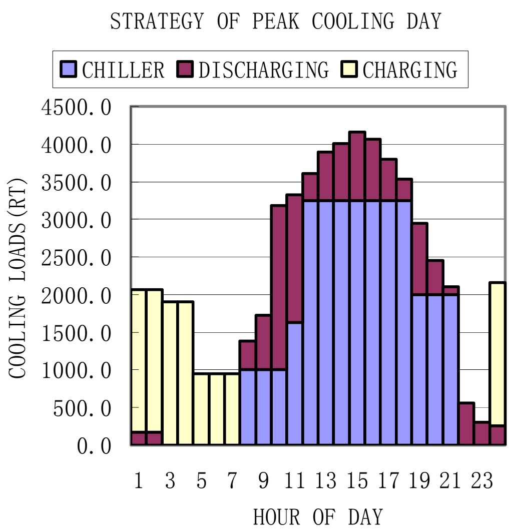
According exploration in this area, the fourth aquifer belongs to infirm endured press area, the groundwater supply condition is very good and the number of groundwater is enormous. The thickness of containing water layer under the ground within 100 meters attains 30~45 meters. The water layer of constant temperature lies in 30 meters underground and the temperature is 15~18□. The result of exploration indicates that Groundwater Source Heat Pump system applied to this project is feasible.

Based on the three-price time-of-use electricity rate structure, we applied Water Thermal Energy Storage to this project to reduce the operating cost. The WTES system can be used in cooling or heating days, but it is necessary to occupy much more building room for WTES because it belongs to sensible energy storage and its energy density is low. This project lies in suburb and the second underground floor has very little commercial value, so the water storage is set up in this floor and the fire protection flume is made use of as parts of water thermal storage to reduce initial cost.

According to analysis, the scheme two can be applied to this project in principle. Groundwater Source Heat Pump and water thermal storage can be integrated to create great benefits.

3.2.2 Scheme design

In this scheme, on peak load day, the mode of charging storage will be operated during the off-peak electrical rate period and during the on-peak load period the water storage will discharge energy to level off peak load. During the on-peak electrical rate period the mode of storage-priority will be operated and the mode of chiller-priority control will be applied during the middle electrical rate period. At the same time, it must be considered that the chiller and the Heat Pump units can operate on the efficient and stable condition. The operating strategies of the scheme two as Fig.1.



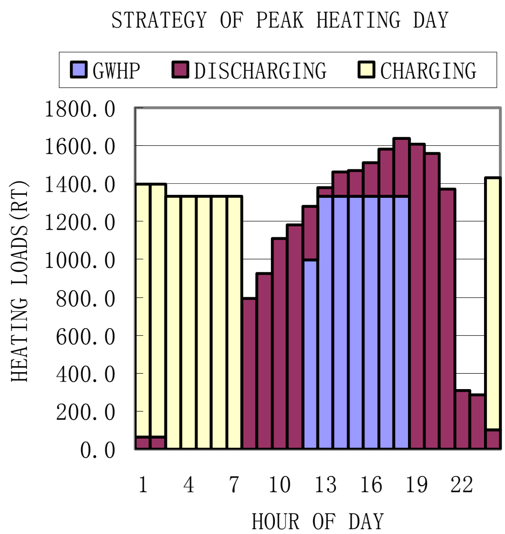


Fig.1 The operating strategies of scheme two

According to the load characteristic and the operating strategy of peak load day, two 1000RT(3517KW) three-stage centrifugal chillers and four Heat Pump Units (313RT for cooling, 333RT for heating) located at the second underground floor. Under design conditions, the fully charged thermal storage tank can hold a cooling capacity of 12350RTh and a heating capacity of 10656RTh. The storage tank has a volume of 6000 stere (including 500 stere of the fire protection flume) and an area of 1333 square meters. Four operating pressure 0.8MPa plate heat exchangers are necessary. Other equipments as Tab.2. The graph of cooling (heating) source system for the scheme two as Fig.2.

3.2.3 Well design

According to cooling principle of water-source heat pump unit, every three high cooling values need to waste one unit of compressor power and four cooling values of underground water. The cooling capacity provided by underground water in summer is Q=14643*4/3 KW =19524KW.

Tab.2: The equipments of scheme two

Equipment	Number	Electric motor power (KW)	Flow (m^3/h)
Main chilled water pump_1	2	45	650
Main chilled water pump_2	4	18.5	230
Cooling water pump_1	2	18.5	260
Cooling water pump_2	4	11	86.6
Chilled water distribution pump	3	37	600

In terms of Q=V·□T·1.163, □T represents supply and return underground-water temperature difference, here □T=15□. It can be calculated that cooling capacity of underground-water in summer is V =1119.2 m^3/h, that is the maximum water volume of demand is 1119.2 m3/h. By analyzing of geology condition and project character in this zone, it can be decided to arrange 8 wells and 16 recharge wells around the building structure, which distance between each two well is 30m.

This project adopts two-pipe system during the distance of every well and machine room's piping network. It can make it available change draw well into recharge well, or make recharge well into draw well. Thereby it can solve the problem of recharge well block.

4. ECNOMIC ANALYSIS

4.1 Initial Investment Comparison

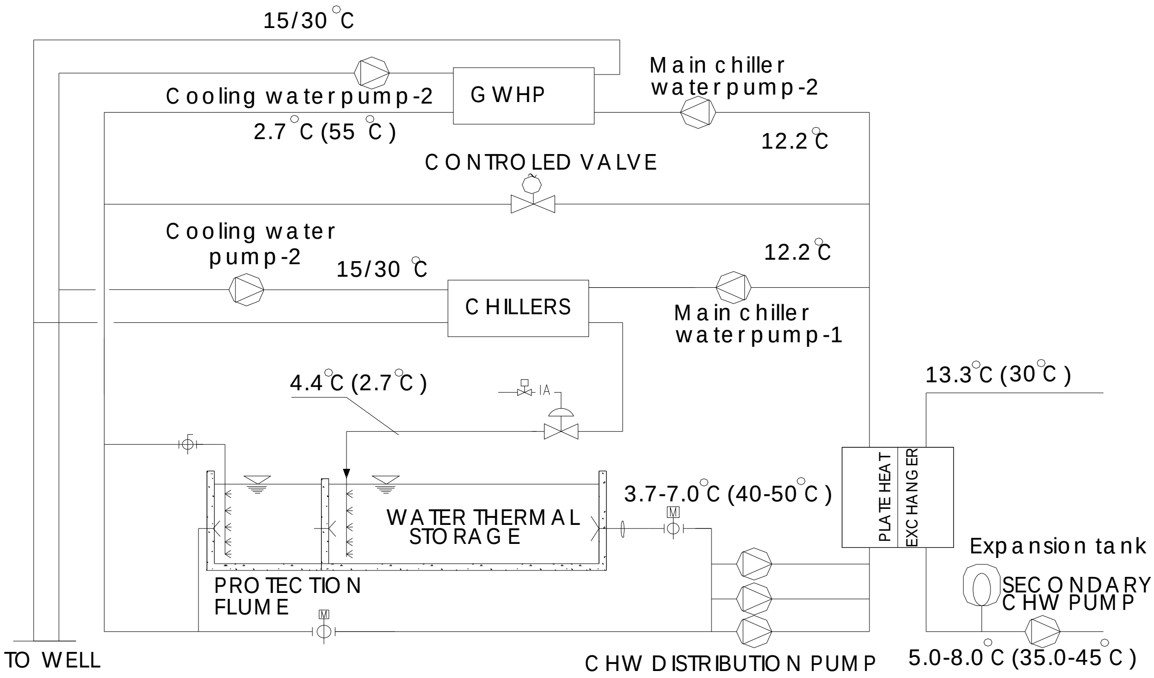


Fig. 2: The cooling and heating source system

Tab.3 Initial investment comparison

NO.	Cost Items	Scheme two (10,000RMB)	Scheme one(10,000RMB)
1	Construction static section	1755.17	1506.84
1.1	Purchasing machine cost	873.30	1115.10
1.2	Architectural engineering cost	624.51	116.51
1.2.1	Machine room architectural engineering cost	84.51	116.51
1.2.2	Water storage tank construction	180.00	0.00
1.2.3	Well construction	360.00	0.00
1.3	Installation cost	169.57	216.52
1.4	Other construction cost	56.56	52.88
1.5	Basic preparation fee	31.23	5.83
2	Construction dynamic section	101.10	86.79
2.1	Reserve for escalation	0.00	0.00
2.2	Interest for construction loan	101.10	86.79
Initial Investment		**1856.27**	**1593.63**

Tab.3 reveals the investment comparison of scheme one and scheme two. Compared with conventional system which employs electric refrigeration and gas-fired boiler system, water source heat pump with water thermal storage system initial investment adds RMB2, 626,400.

4.2 Operating Cost Analysis

Thermal Energy Storage system should calculate annual operating cost on the basis of load ratio and operating strategy. In the stage of design, in terms of annual average load ratio, as shown in Tab.4, TES system stores thermal storage at off-peak hour. It runs compressor aided operation at on-peak hour. By adjusting control operating strategy, operating electricity cost can be computed. Fig.5 shows Beijing commercial electricity price (less than 1000 volt). Operating cost both scheme one and scheme two is described in Tab.6. From the comparison we can see that scheme two reduce operating cost RMB3, 310,100.

Because of auxiliary project, there is no cash flow. This paper uses operating cost comparison method to analyze cash flow, which sees the less operating cost difference as the cash flow in of the less one, and then regards initial investment difference as initial investment to calculate. While the saving accumulated net cash flow value is more than initial investment difference, it dictates this project is feasible in economy. That is, $\sum_{t=0}^{25}\left(NPV_{scheme\ two}-NPV_{scheme\ one}\right)\geq 0$, it denotes that scheme two is better than scheme one. IRR is served as 15% here. Through calculating we can get ∑NPV=2611.23 > 0, which reveals scheme two is much more advantage. Though the initial investment of scheme two is more than the scheme one, the effective control strategy makes the operating cost much less. What's more, the first saving cost is enough to recycle the initial investment. It explicitly denotes the feasibility of water source heat pump and thermal energy system in economy.

5．SOCIAL BENEFIT ANALYSIS

Tab.4 Load ratio distribution

Load ratio	Number of cooling load days	Number of heating load days
100%	21	21
80%	61	49
60%	61	21
40%	71	10
25%	0	20

Compared with conventional system, under-ground water source heat pump with water thermal storage system can lower the on-peak hour power demand and improve the efficiency of power plant. It also can reduce combustion air emission. This project shifted electric power 1285KW, as figured out, it can reduce annual coal consumption 771 ton (standard coal), lower combustion air emission including SO2 5.07 ton, CO2 1014.47 ton and 8.52 ton dust.

Tab.5 Time-of-use electricity rate structure in Beijing

Structure	Period of time	Electricity rate （RMB/KWh）
On-peak period	8:00-11:00 18:00-23:00	1.077
Mid-peak period	7:00-8:00 11:00-18:00	0.688
Off-peak period	23:00-7:00	0.322

It has no cooling tower, the influence of noise is too limited. Because it utilizes closed exchanging system, obviously there is no floating and air pollution. Also it couldn't need water to compensate. Scheme two has no combustion air emission than the conventional gas-fired boiler heating system. So it puts a dominating role in environmental protection. Underground-water heat pump system employs low-cost heat and auxiliary electric power, the COP can reach to 3~4, which saves primary source and improves source efficiency.

6．CONCLUTSIONS

According to the project character and geological condition, this paper compares the conventional system (scheme one) with the underground water heat pump and water thermal storage system (scheme two). The conclusion is shown below.

1)Scheme one is mature in technology, operating stably and being used extensively. Scheme two is feasible in technology, however, it needs complex.

control strategy and recharging skill to ensure equal volume underground water recharge into the same geological layer

2)Scheme two is more advantage than scheme one in economy.

3)Scheme two also can shift more electric power at each on-peak hour and rises primary source efficiency rate. Therefore, it not only can protect environment and save energy but also can extremely increase social benefits.

Tab.6 Operating cost comparison

NO.	Item	Scheme two (10,000RMB)	Scheme one (10,000RMB)
一	Fixed cost	41.85	46.77
1	Repairing cost	14.85	10.77
2	Production personnel wages	27.00	36.00
二	Changeable cost	359.81	685.90
1	Electric cost	359.81	449.06
2	Gas cost	0.00	196.84
3	Water/Chemical cost	0.00	40.00
	Total Operating cost (10,000RMB)	401.66	732.67

In summary, underground-water heat pump with water thermal storage is economical, environment-friendly and efficient cooling and heating source system in this project. This study has a positive role in promoting our country’s development of thermal storage air-conditioning.

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